

Comments on Phys. Rev. D89, 097101 (2014)

“Reevaluation of the parton distribution of strange quarks in the nucleon”

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Abstract

The HERMES collaboration in Phys. Rev. D89, 097101 (2014) extracted information about the strange quark density in the nucleon. One of the main results is an observation that the shape of the extracted density is very different from the shapes of the strange quark density from global QCD fits and also from that of the light antiquarks.

In this paper systematic studies on the HERMES published multiplicity of pion and kaon data are presented. It is shown that the conclusions concerning the strange quark distribution in the nucleon reached in Phys. Rev. D89, 097101 (2014) are at the moment premature.

1 INTRODUCTION

The information on the strange quark properties in the nucleon is rather scarce. The HERMES results [1] on semi inclusive deep inelastic scattering should bring a very important contribution to this problem. The collaboration recently confirmed a previous claim [2] that the strange quark parton distribution function (PDF) has very different shape in the Bjorken x scaling variable as compared to the distribution of non-strange sea. This statement has deep impact in the field.

Unfortunately both HERMES analyses [1] and [2] are based solely on the study of the kaon multiplicity sum, without presenting any further systematic checks. In this paper, after a brief explanation of the HERMES analysis method, the pion multiplicity sum is discussed. As a self consistency check for the results obtained using the kaon multiplicity sum, a different combination of K^+ and K^- multiplicity is also studied. Finally, the results concerning the kaon multiplicity difference are presented.

2 THE HERMES METHOD

HERMES studied the semi-inclusive deep inelastic scattering (SIDIS) of electrons impinging on a deuteron target. The results [1] on the strange quark PDF $S(x)$ are based on the analysis of the sum of multiplicities of charged kaons ($K^+ + K^-$) as a function of Bjorken x , $dN^K(x)/dN^{DIS}(x)$. As stated there, in LO pQCD,

$$\frac{dN^K(x, Q^2)}{dN^{DIS}(x, Q^2)} = \frac{Q(x, Q^2) \int D_Q^K(z, Q^2) dz + S(x, Q^2) \int D_S^K(z, Q^2) dz}{5Q(x, Q^2) + 2S(x, Q^2)}, \quad (1)$$

where Q and S are a combination of non-strange quark densities, $Q = u + \bar{u} + d + \bar{d}$ and of strange ones $S = s + \bar{s}$. The $D_Q^K(z, Q^2)$ is a fragmentation function defined as $D_Q^K(z, Q^2) = 4D_u^K(z, Q^2) + D_d^K(z, Q^2)$, while $D_S^K(z, Q^2) = 2D_s^K(z, Q^2)$. The Q^2 is the negative four momentum transfer and z (in lab. frame) is the fraction of the photon energy carried by the hadron.

As presented in Fig. 1 of [1], the kaon multiplicity is flat for high x , i.e., in the region where a small contribution from strange quarks is expected, and it rises by about 20-30% for lower values of x . Without strange quarks the distribution should be almost flat. Therefore, the increase of the kaon multiplicity sum in the low x region is interpreted as a strong signature of the strange quarks presence (see Figs. 2, 3 in Ref. [1]). In addition the x dependence of the kaon multiplicity sum suggests that the shapes of the strange and non-strange sea are very different.

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3 SYSTEMATIC STUDIES

3.1 The π multiplicity sum

The multiplicity analyses are quite complex as they depend a lot on various correction factors. For this reason before claiming certain features of the strange quark distribution using kaon multiplicities, as a natural self consistency check the pion results should be verified. The multiplicity sum of pions can be written in a similar way as in Eq.(1),

$$\frac{dN^\pi}{dN^{DIS}} = \frac{Q D_Q^\pi + S D_S^\pi}{5Q + 2S}, \quad (2)$$

where D_Q^π and D_S^π are the pion fragmentation functions defined in a similar way as for kaons. Here for simplicity the x , Q^2 , z dependence was omitted and $D_i^\pi = \int D_i^\pi(z, Q^2) dz$. The Eq. (2) can be re-written in the following form:

$$\frac{dN^\pi}{dN^{DIS}} = \frac{D_Q^\pi}{5} + \frac{S}{5Q + 2S} (D_S^\pi - 0.4D_Q^\pi). \quad (3)$$

It is interesting to notice that:

$$D_S^\pi - 0.4D_Q^\pi = 2D_s^\pi - 1.6D_u^\pi - 0.4D_d^\pi < 0. \quad (4)$$

The right hand side of Eq.(4) is expected to be *negative* since D_u^π and D_d^π involve the so called favored fragmentation functions $D_u^{\pi^+}$ and $D_d^{\pi^-}$. In LO, due to the presence of strange quarks, the pion multiplicity sum should decrease for lower values of x , contrary to the kaon case.

The π multiplicity sum can be extracted from the published HERMES data [3]. The result is shown on the left panel of Fig. 1, using x representation of the data (vector meson subtracted), the presented systematic uncertainty band takes into account the correlation factors between systematic uncertainties of the π^+ , π^- data. These correlation factors were obtained indirectly from the published uncertainties of M^{π^+} , M^{π^-} and $(M^{\pi^+} - M^{\pi^-})/(M^{\pi^+} + M^{\pi^-})$. Correlation factors were also extracted for the kaon case, where they reach a value up to 0.85. Contrary to the expectations (*cf.* above) the shape of the distribution is very similar to the one of the K multiplicity sum, presented in the right panel of Fig. 1. For easier comparison the kaon multiplicity sum was multiplied by a factor 6.4, which minimizes the χ^2 between π and K multiplicity sums: a value of $\chi^2/ndf = 5.1/8$ in the case when the correlation between positive and negative particles is taken into account as described above, or $\chi^2/ndf = 7.7/8$ in the case when systematic uncertainties are treated as independent. Especially interesting is the fact that both multiplicities start to rise more or less at the same x . In [1], the increase for kaons is attributed solely to the strange quark PDF having very different shape from the non-strange sea. But as presented here, such an explanation does not work for the π data. On the other hand, very similar shape of the distributions suggests that there is a common source which causes the observed effect.

The Q^2 dependence of D_Q^π in both LO and NLO is expected to be rather weak in the region of interest. Thus it cannot explain the features observed in the left panel of Fig 1. In the DSS fit of fragmentation functions [4], both in LO and NLO $D_Q^\pi(Q^2 = 1\text{GeV}^2) < D_Q^\pi(Q^2 = 3\text{GeV}^2)$. The lowest HERMES x corresponds to $\langle Q^2 \rangle \approx 1.2 \text{ GeV}^2$, while $\langle Q^2 \rangle = 3 \text{ GeV}^2$ for $x \approx 0.15$. The weak Q^2 dependence is also seen in HERMES data in the Q^2 representation. The pion multiplicity sum is basically flat in the full Q^2 range with an average $dN^\pi/dN^{DIS} = 0.717$. So the effect presented in the left panel of Fig. 1 is indeed related to x or y dependence, and not Q^2 .

It is worth to mention that in Ref. [5] problems with the perturbative description of HERMES pion data in LO and NLO are discussed. Moreover, as noted by the same authors in [6], the analyses of HERMES multiplicity data available in x and Q^2 representations do not give compatible results. For example for x representation at $x = 0.17$ and $Q^2 = 3.2 \text{ GeV}^2$ the π multiplicity sum is: $0.675 \pm 0.002 \pm 0.006$. For almost the same kinematic point, $x = 0.17$ and $Q^2 = 3.8 \text{ GeV}^2$, but in Q^2 representation, the π multiplicity sum is $0.714 \pm 0.002 \pm 0.007$. A difference of about 6% is seen. It is much larger than statistical and systematic uncertainties, while a large part of the data is the same. Observe that the average x value of the presented data points is high enough, so that the point in Q^2 representation doesn't contain low x data ($x < 0.08$), whose presence could otherwise explain the observed difference. In my opinion the HERMES multiplicities should be available simultaneously in (x, y, z) or (x, Q^2, z) representations so that such effects can be studied in more details. In what follows it is assumed that the current HERMES results in x representation were extracted correctly from the data.

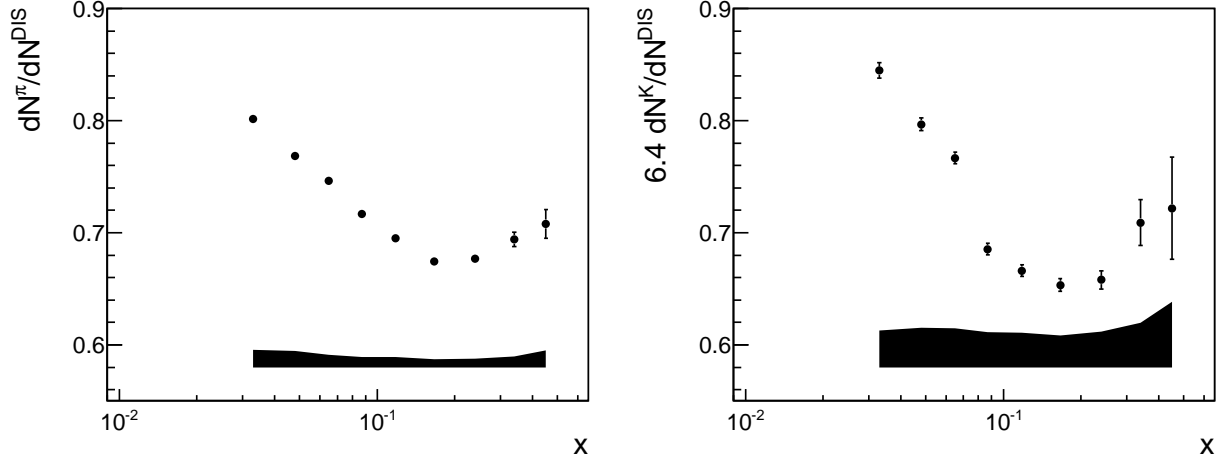


Figure 1: Comparison of π and K multiplicity sums obtained from [3], left and right panels respectively. Striking and not expected similarities in shape are observed.

3.2 Kaon multiplicities

The analysis of the strange quark content of the nucleon using the kaon multiplicity sum is one of many possible choices. For a self consistency check one can use other combinations of K^+ and K^- multiplicities. The drawback is that to have a simple formula one has to assume in addition that $s(x) = \bar{s}(x)$ ¹. One such possible choice is to cancel the contribution from $D_u^{K^+}$ in the expression for the multiplicity. The starting point is the kaon multiplicity difference (see Ref. [8]),

$$\frac{dN^{K^{diff}}}{dN^{DIS}} = \frac{(u_v + d_v)(4D_u^{K^+} - 4D_{\bar{u}}^{K^+} + D_d^{K^+} - D_{\bar{d}}^{K^+})}{5Q + 2S}. \quad (5)$$

To have a common notation, Eq.(1) can be rewritten as

$$\frac{dN^K}{dN^{DIS}} = \frac{Q(4D_u^{K^+} + 4D_{\bar{u}}^{K^+} + D_d^{K^+} + D_{\bar{d}}^{K^+}) + SD_S^K}{5Q + 2S}. \quad (6)$$

Combining Eq.(5) and Eq.(6) one obtains

$$\frac{5Q + 2S}{Q} \frac{dN^K}{dN^{DIS}} - \frac{5Q + 2S}{u_v + d_v} \frac{dN^{K^{diff}}}{dN^{DIS}} = \frac{dN^{K'}}{dN^{DIS}} = 8D_{\bar{u}}^{K^+} + 2D_{\bar{d}}^{K^+} + \frac{S}{Q} D_S^K. \quad (7)$$

The idea of the analysis is exactly the same as for the kaon multiplicity sum. Namely an increase of the multiplicity should be observed for low x , due to the increased strange quark presence. Moreover, as in the original idea of the HERMES analysis in Ref. [1] one does not need to know separately $D_{\bar{u}}^{K^+}$ and $D_{\bar{d}}^{K^+}$, but only their combination presented in Eq.(7). This combination is extracted from the data at high x , exactly as was done for D_Q^K in [1]. Based on the results presented in Fig. 3 of [1], at lowest x one expects a rise of $dN^{K'}/dN^{DIS}$ due to SD_S^K/Q by about 0.18. The actual results of $dN^{K'}/dN^{DIS}$ are presented in the left panel of Fig. 2. The MSTW08 LO PDF [7] was used in the evaluation of results. Contrary to the expectations, the multiplicity decreases. As it is hard to expect that the Q^2 dependence of $D_{\bar{u}}^{K^+} + D_{\bar{d}}^{K^+}$ can fully explain the shape presented in Fig. 2, this is an indication of a failure of the conventional LO pQCD parton model approach in the analysis of multiplicities at HERMES kinematics, see also Ref. [9]. For completeness, the extraction of $dN^{K'}/dN^{DIS}$ using NNPDF30L [10] was also added on Fig. 2. The gray band marks $\pm 1\sigma$ of the NNPDF30L uncertainty. Finally, a set of lines corresponds to the expected value of

¹It was verified that not using $s = \bar{s}$ assumption, but strange quark densities as in MSTW08 LO PDF [7], the conclusions presented later are not changed.

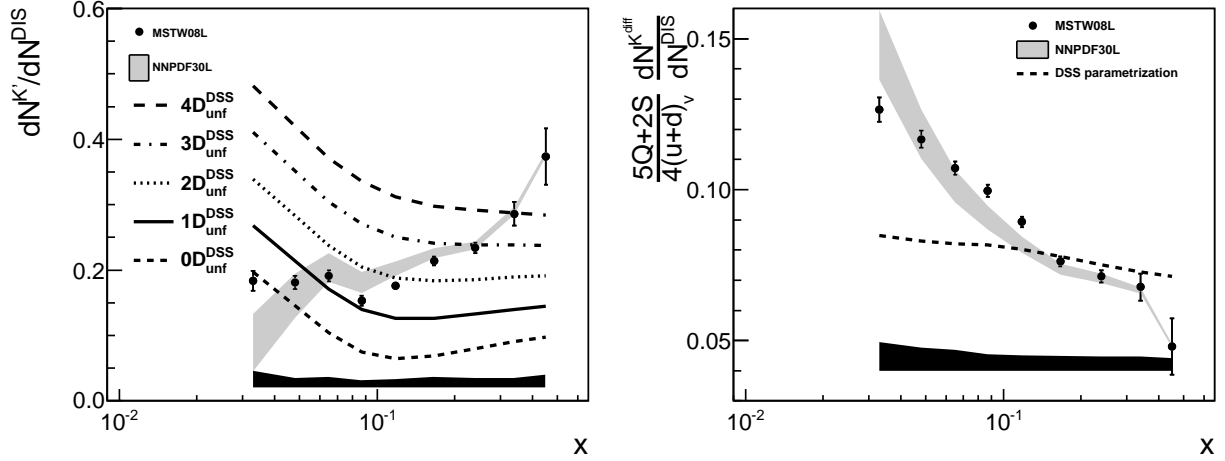


Figure 2: Left panel: A tentative of extraction of the strange quark contribution in the nucleon using a certain combination of K^+ and K^- multiplicities (K'), where the contribution from $D_u^{K^+}$ cancels. A drop of the multiplicity at low x is observed instead of the expected rise. The points correspond to the K' extraction using MSTW08 LO, and black band on the bottom marks systematic uncertainty of data. The K' was also extracted using NNPDF30L set, the gray band it the $\pm 1\sigma$ uncertainty of NNPDF30L. Finally, a set of lines corresponds to the LO prediction for K' , where on top of extracted from HERMES $S(x) \int D_{str}$ distribution (divided by Q) a $10D_{unf}^{DSS}$ is added with additional scaling factors applied at the reference scale. Right panel: Comparison of the kaon multiplicity difference in the HERMES data multiplied by $(5Q + 2S)/4(u_v + d_v)$ with the DSS expectation.

$dN^{K'}/dN^{DIS}$ in LO, assuming $S(x) \int D_{str}$ as extracted by HERMES and a DSS parametrization of D_{unf} , which at the reference scale was multiplied by a factor in the range $\in (0, 4)$. To perform the Q^2 evolution of the re-scaled FF a QCDNUM program was used [11].

The problem presented in the left panel of Fig. 2 is also seen while studying just the kaon multiplicity difference. As can be deduced from Eq.(5) under the assumption $s(x) = \bar{s}(x)$, the kaon multiplicity difference does not depend upon the strange quarks density, but it is obviously correlated with D_Q^K . Multiplying the kaon multiplicity difference by $(5Q + 2S)/4(u_v + d_v)$, one effectively obtains what in the DSS fit can be related to the difference of the so called favored and unfavored FF (observe that in DSS $D_d^{K^+} - D_d^{K^-} = 0$). According to the DSS fit this combination has a weak Q^2 dependence of about 10%. What is actually found in the HERMES data using x representation (vector meson subtracted) is presented in the right panel of Fig. 2. There is a clear disagreement between the HERMES data and the weak Q^2 dependence expected from the DSS fit. For completeness the exercise was repeated with NNPDF30L set, $\pm 1\sigma$ of PDF uncertainty around extracted values is shown as a gray band on the right panel of Fig. 2.

The $dN^{K^{diff}}/dN^{DIS}$ is strongly correlated with D_Q^K , i.e., in LO pQCD, assuming $s(x) = \bar{s}(x)$, D_Q^K can be expressed as a function of $dN^{K^{diff}}/dN^{DIS} \cdot (5Q + 2S)/(u_v + d_v)$ and some unfavored FF. One cannot assume that the reason causing the unexpected x dependence of $dN^{K^{diff}}/dN^{DIS}$ is not affecting the extraction of D_Q^K . In such a situation using Eq.(1) to extract $S D_S^K$ as done in [1] is not justified. It is also clear that even if one tries to explain the observed rise in the kaon multiplicity sum as solely related to the strange quarks, the observed features in the kaon multiplicity difference, $dN^{K'}/dN^{DIS}$, and in the π multiplicity sum will not be explained.

4 SUMMARY

It is possible that the strange quark distribution in the nucleon has indeed different shape than the non-strange sea. However, the tests presented in this paper indicate that the analysis of HERMES data [3] based on the conventional LO pQCD parton model approach cannot be used to support the final conclusion of their

paper [1]. Namely that the shape of $xS(x, Q^2)$ is strikingly different from that of global QCD fits and the sum of the light antiquarks. The above conclusion assumes that multiplicities published in [3] were extracted correctly from the data. It would be clearly beneficial to the community if HERMES multiplicity data were available simultaneously in (x, Q^2, z) or (x, y, z) intervals so that more systematic tests could be done in the future.

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